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# X-Band RF Structures Cooling

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# 1. Introduction

The scope of this note is to describe a simple method that allows determining the range in which the cooling system parameters can be modified while maintaining the correct operational parameters of X-Band RF structures for a Linear Collider. This procedure is based on the numerical analysis of the RF structures cooling presented in TD-04-020.

# 2. Cooling Parameters

In order to generate an unloaded accelerating gradient of 65 MV/m, a structure requires a peak input power of 56MW. The effective length of the pulse is 400ns with a repetition rate of 120 Hz. Assuming that the lost power is around 63% of the input value, using the following equation 1:

$$P = P_{in} \frac{t}{0.8} f \frac{\eta}{L} \tag{1}$$

Where:

| | |
|---|---|
| P | is the total power to be absorbed by the cooling water [W] |
| $P_{in}$ | is the input peak power [W] |
| t | is the pulse length [s] |
| f | is the repetition rate [Hz] |
| η | is the percentage of the power adsorbed by the structure with beam off |
| L | is the length of the structure [m] |

it is possible to determine the heat load in the structure, which is about 3.5 kW/m.
The average temperature of the RF wall of the structure (in our case the inner diameter of the disk) must be kept near 45 C. This value presented in the NLC baseline design results in the best electrical properties of copper [1].
The input temperature of the cooling water is defined by the whole accelerator cooling system. In the baseline design of the accelerator, cooling towers are used to compensate for the temperature rise of the water in the system. The optimal working point for the cooling towers depends on their geographical location. In this case, the worst scenario is the Californian site of the machine, where the lowest attinable temperature of the cooling water is 82 F (~28 C).

# 3. Heat Exchange Coefficient

Given the above cooling parameters, it is possible to calculate the heat exchange coefficient as a function of the chosen flow and temperature rise of the cooling water. As described in the previous note, the RF structures are cooled using four pipes in 2 separate circuits and each circuit uses a counterflow configuration. The water properties are evaluated at the inlet temperature, but since for the power balance only the temperature rise is fixed, a reference temperature of 30 C was chosen.
As verified, the flow in each analyzed configuration is always turbulent, so the heat exchange coefficient can be calculated as follows using equation 2:

$$h = 0.023\frac{\lambda}{d}\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} \qquad (2)$$

Where

h is the heat exchange coefficient [$W/m^2K$]

d is the pipe diameter [m]

λ is the water thermal conductivity [W/mK]

Re is Reynolds number

Pr is Prandtl number

The power balance for the heat exchange is:

$$P = c \cdot m(\Delta T) \qquad (3)$$

Where:

P is power [W]

m is the mass flow [Kg/s]

ΔT is the temperature rise [C]

c is the water heat capacity [J/Kg K]

The results are shown in table 1:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| P | W | 3500 | 3500 | 3500 | 3500 | 3500 | 3500 | 3500 |
| T ref | C | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| d | m | 0.01587 | 0.01587 | 0.01587 | 0.01587 | 0.01587 | 0.01587 | 0.01587 |
| a | m2 | 0.000198 | 0.000198 | 0.000198 | 0.000198 | 0.000198 | 0.000198 | 0.000198 |
| ΔT | C | 1.5 | 2 | 3 | 4 | 5 | 6 | 7 |
| Flow | Kg/s | 0.5584 | 0.4188 | 0.2792 | 0.2094 | 0.1675 | 0.1396 | 0.1197 |
| GPM | GPM | 8.8639 | 6.6479 | 4.432 | 3.324 | 2.659 | 2.216 | 1.899 |
| v | m/s | 1.4118 | 1.0589 | 0.7059 | 0.5294 | 0.4236 | 0.353 | 0.3025 |
| Re | - | 27965 | 20974 | 13980 | 10487 | 8389 | 6991 | 5992 |
| Pr | - | 5.4162 | 5.4162 | 5.4162 | 5.4162 | 5.4162 | 5.4162 | 5.4162 |
| h | $W/m^2K$ | 6325 | 5025 | 3633 | 2886 | 2414 | 2087 | 1845 |

Table 1 Heat exchange coefficient

# 4. Cooling Parameters working-space

Table 1 shows the impact of the velocity in the cooling pipes on the heat exchange coefficient between water and copper. As a result, the lower the heat exchange, for a constant contact area, the higher must be kept the differential temperature between copper and water. The plot shown in figure 1 allows defining all the cooling parameters given a specified temperature at the RF wall of the structures. The plot is obtained using the same thermal calculations used to generate table 1, plus the numeric code described in TD-04-020 to calculate the temperature distribution through the RF structure cross section

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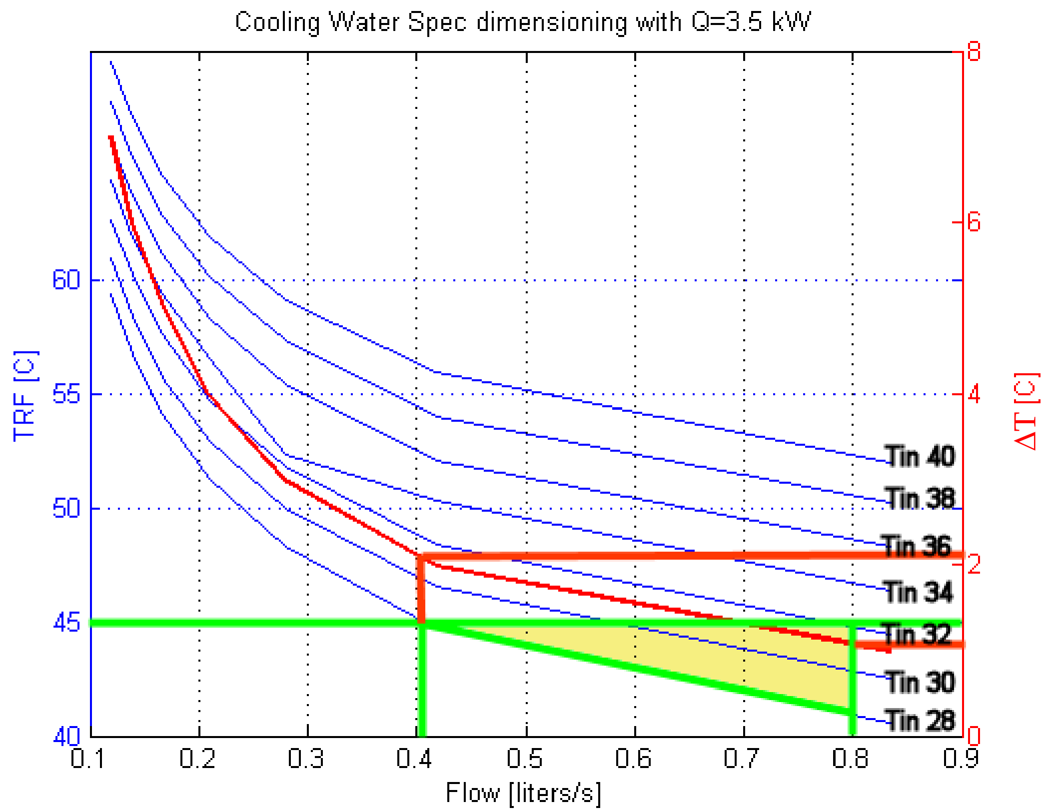


Figure 1 RF Structures cooling

*4.1. How to read Figure 1*

The plot shows on the same area two different types of curves. Reading on the left side one finds the correlation between the temperature of the RF wall (TRF) and the flow rate by choosing one of the blue curves. Each of the blue curves corresponds to a different inlet temperature of the cooling water (Tin, between 28 C and 40 C).

Reading on the right side one finds the correlation between the flow rate and the temperature rise in the water by moving on the red curve. One can choose a TRF and a Tin and define the flow rate; then, given the flow rate, it is possible to use the red curve to define the correct temperature rise in the cooling water. As an example, if TRF is 45 C and Tin is 28 C the correct flow rate would be ~0.4 liters/s and the water temperature rise around 2 C.

*4.2 Parameters working-space*

Assuming a temperature of the RF wall of 45 C and a lower limit for the cooling water of 28 C, a rather narrow region in figure 1, marked in yellow, defines the possible combinations of parameters that satisfy the optimal working conditions of the structures. The limit on the flow rate is given by the pressure loss in the pipes when the velocity is too high. For practical conditions, the flow rate should be between 0.4 and 0.8 liters/s (6.3 and 12.6 GPM) while the temperature rise in the water should be between 1 and 2 C. In this case the inlet temperature of the cooling water would be between 28 and 32 C.

# Conclusions

Given the actual design of the X-Band RF structures, a simple plot that allows determining the optimal combinations of the parameters for the cooling system has been generated.